Can Delta Smelt Swim in the Dark?

Paciencia S. Young, Christina Swanson, and Joseph J. Cech, Jr. (University of California, Davis)

Delta smelt, *Hypomesus transpacificus*, is a small, estuarine osmerid native to the Sacramento-San Joaquin estuary. During the drought years of the mid-80s to early 90s, the delta smelt population has declined an estimated 90 percent, and the fish was listed by both the federal and state governments as threatened. Entrainment and impingement of young and adult delta smelt in water diversions are considered a possible contributing factor to their population decline. Some water diversions in the delta operate 24 hours a day. No studies had been conducted to find out if delta smelt are more susceptible to entrainment or impingement in the dark than in the light or during the night than during the day. As part of a large study on delta smelt swimming performance, the objective of which is to provide information for developing water diversion approach velocity criteria, we conducted experiments to answer the following questions:

- Do delta smelt swim as well under dark condition as under lighted condition?
- Do delta smelt swim as well during nighttime as during daytime?
- If their swimming is impaired at night, will illumination help delta smelt swimming performance?

Most of the delta smelt used for the study were collected at Grizzly Bay and Suisun Cut on August 14-16, 1995. They were brought to the UC-Davis laboratory and were acclimated to 17°C. The fish measured 4.0-5.9mm standard length. Swimming performance was measured in terms of critical swimming velocity (U_{crit}) using a Brett-type swimming flume enclosed in a black plastic structure to exclude outside light and any distraction that might disturb the fish. A light source with two fluorescent bulbs was directed toward a 3m x 1m white reflecting panel, yielding a light intensity of 50-60 lux in the swimming chamber. A video camera was mounted above the flume, and fish activity was observed through a monitor situated outside the black structure. Under dark conditions, the lights were turned off and observations were made inside the black structure using infrared-sensitive night-vision goggles. Individual fish were placed in the chamber and, after 1 hour habituation, water velocity was increased by 3 cm/s every 10 minutes, starting at 6 cm/s, until fish were fatigued (impinged three times at the downstream end of the chamber). U_{crit} (cm/s) was calculated using: $U_{crit} = U_i + (3 \text{ cm/s} \times T_i/10 \text{ min})$ where: U_i = highest velocity (cm/s) maintained for the prescribed time period, and T_i = time (min) elapsed at fatigue velocity. Fish swimming performance was measured under two photophase conditions: during daytime between 0800 and 1700 hours and during nighttime between 1900 and 2200 hours, and under light intensity of 50-60 lux and in complete darkness (0 lux).

Regardless of illumination and photophase condition 30-33 percent of the delta smelt were unable to swim in the flume. Results of those that did swim show that during daytime under light conditions, mean U_{crit} was 28 cm/s (Figure 1). Under dark conditions, swimming performance was significantly impaired. During nighttime under light conditions, swimming performance was significantly lower compared to that during daytime under light conditions but not significantly different than under daytime dark conditions. During nighttime under dark conditions, swimming performance was even worse and significantly lower than during daytime under dark conditions.

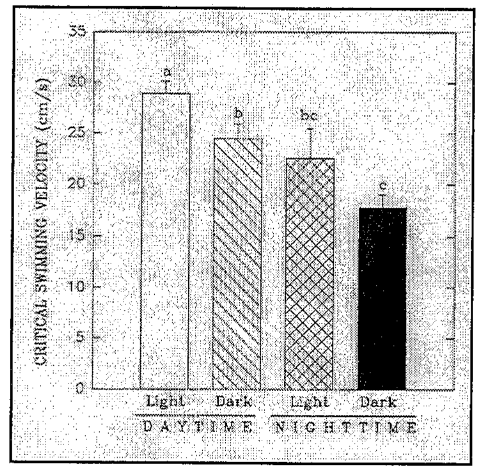

Figure 1
MEAN CRITICAL SWIMMING VELOCITY DURING TWO PHOTOPHASES AND UNDER TWO LIGHT CONDITIONS
Symbols with different letters are significantly different at P<0.05. N=6-14

These experiments show that two factors affect delta smelt swimming performance — illumination and photophase — and both must be present for maximum swimming performance. If a water diversion operates 24 hours a day, it is likely that delta smelt are most susceptible to entrainment and impingement at night. Our results also suggest that presence of 50-60 lux illumination at night does not significantly improve delta smelt swimming performance.

To find out if the use of light intensities other than 50-60 lux during night operation of delta water export pumps will help delta smelt perceive and better react to their environment, we have to find out first how delta smelt behave (eg, attracted to light or not) near fish screens under these different light intensities. These studies should simulate reality (eg, with complex flow fields, multi-individual groups of delta smelt, presence of predators, and other relevant factors included) as closely as possible using methods and equipment (eg, fish treadmill) that simulate environmental conditions like those near water diversions in the delta.

This study was funded by the Department of Water Resources, facilitated by R. Brown, D. Hayes, and T. Frink. Delta smelt collection was made possible with the assistance from the Department of Fish and Game, through cooperation from D. Sweetnam, G. Aasen, J. Lott, and the bay/delta boat crew. We thank M. Gonzales, D. Irwin, T. Frink, K. Kroll, R. Mager, D. Shigematsu, M. Thibodeau, and S. Vandepeute for assistant in fish collection. We also thank S. Aren, S. Cummings, M. Gonzales, D. Irwin, J. Lorenzo, L. Minium, C. Porter, D. Shigematsu, S. Tannen, M. Thibodeau, and S. Vandepeute for help in fish care, maintenance, and fish swimming. We also thank P. Lutes and B. Bentley of the UC-Davis Aquaculture and Fisheries Program for advice on our water supply system and for maintenance of our water and air systems.

Swimming Performance of Delta Smelt

Christina Swanson, Paciencia S. Young, and Joseph J. Cech, Jr. (University of California, Davis)

Entrainment of delta smelt (*Hypomesus transpacificus*) in water diversions may have been a factor in the population decline of this fish observed in the drought years of the mid-1980s through early 1990s (Moyle *et al* 1992; USFWS 1994). Currently, water diversion flow regulations in the delta are based on data from other species (American shad and chinook salmon). In 1993, we began research on swimming performance and behavior of delta smelt to provide information use in developing approach velocity criteria appropriate for this species.

Delta smelt swimming performance was measured in terms of critical swimming velocity (U_{crit}, cm/s), the maximum velocity a fish can maintain for a specified amount of time; and endurance (min), the length of time a fish can sustain swimming at a constant velocity (Brett 1964). These two indices of swimming performance have been used to develop approach velocities for a number of species, including salmonids and striped bass (Clay 1995). For both experiment types, the endpoint was fatigue, indicated by the fish failing to hold position against the current and becoming impinged repeatedly on the downstream screen of the swimming flume. Experiments were conducted using juvenile (<4.5 cm standard length), subadult (4.5-5.9 cm standard length), and adult delta smelt (≥6.0 cm standard length) acclimated to temperatures of 12-21°C in fresh water (0 ppt), in a laminar flow, Brett-type swimming flume.

Delta smelt are extremely sensitive to stress and confinement (Swanson and Cech 1995). Many fish had difficulty swimming in the flume; 29-39% of the fish failed to swim adequately, became impinged repeatedly on the flume screen at submaximal velocities, and did not yield a U_{crit} or endurance measurement. In the U_{crit} experiments, 55% of the fish that swam to the experimental endpoint became impinged temporarily at submaximal velocities; the velocity at which these fish first became impinged was designated U_{imp1} (cm/s). In the endurance experiments, delta smelt frequently became impinged temporarily but then continued swimming for an extended period; the time (minutes) of the first incidence of impingement was designated Imp1.

Critical swimming velocity (Table 1) was not affected by acclimation temperature or fish size (both tests, $p > 0.1$); mean maximum swimming velocity of delta smelt was 27 ± 6 cm/s. Uimp1 was not affected by temperature ($p > 0.1$) but increased slightly with increases in size ($p < 0.05$). However, the proportion of fish that became temporarily impinged at submaximal velocities decreased with increases in fish size ($p < 0.05$); juvenile delta smelt impinged at low velocities more frequently than large adult delta smelt.

Table 1
CRITICAL SWIMMING VELOCITY (U_{crit}, cm/s, mean±SD), VELOCITY AT TIME OF FIRST IMPINGEMENT (Uimp1), AND PERCENTAGE OF FISH IMPINGED AT SUBMAXIMAL VELOCITY OF DELTA SMELT

Stage (SL)	U_{crit} (n)	U_{imp1} (n)	%
Juvenile (<4.5)	26.7±4.7 (18)	10.2±3.2 (14)	78
Subadult (4.5-5.9)	29.3±5.4 (23)	14.4±2.0 (13)	57
Adult (6.0)	27.5±7.7 (37)	14.5±4.6 (16)	43

Endurance and Imp1 (Table 2) were highly variable; significant effects of temperature, life history stage, and size were not detected (all tests, $p > 0.05$). Both endurance and Imp1 times decreased significantly between 10 and 15 cm/s (both tests, $p<0.01$), but higher velocity (>15 cm/s) had no significant effect on either response (all tests, $p>0.1$). At velocity above 10 cm/s, 50% of delta smelt became impinged within 6-49 minutes and fatigued within 11-64 minutes.

Results of these studies show that, although delta smelt achieved and sustained moderately high maximum swimming velocities (*ie,* U_{crit}), their sustained swimming performance was highly variable and generally poor. Most fish were unable to sustain swimming at velocities above 10 cm/s for more than a few minutes without becoming impinged on the screen in the flume. We believe there are several reasons for this poor performance. First, sensitive delta smelt responded poorly to confinement in the swimming flume. Although we believe the maximum performance responses we measured (*ie,* U_{crit} values and high endurance times) are probably relatively accurate measures of the maximal performance capacity of this fish, the high failure rates (*ie,* fish unable to swim adequately), high rates of impingement at submaximal velocities, and low endurance and Imp1 times at low to moderate velocities probably reflect stress and inability of the fish to express appropriate behavioral responses to the current, such as escape behavior, in the confined flume. Furthermore, a laminar flow swimming flume is a poor simulation of complex flow regimes typical near water diversions (Pearce and Lee 1991). Second, behavioral observations of undisturbed, minimally confined, spontaneously active fish indicate that, unlike many other fishes for which these types of studies have been done (*eg,* salmonids), delta smelt are unsteady, slow swimmers, rarely swimming faster than 10 cm/s (Swanson and Cech 1995). Third, delta smelt exhibit a velocity-dependent change in swimming mode, or gait. At low velocities (≤10 cm/s) the fish swim using a "stroke and glide" mode, alternately stroking and coasting through the water. At velocities above 15 cm/s, the fish shift gaits to swim by stroking continuously. The velocity at which the fish change gaits, between 10 and 15 cm/s, appears to be very stressful to delta smelt, as evidenced by U_{imp1} and the dramatic decrease in endurance and Imp1 times at these velocities. Analyses of the swimming kinematics of delta smelt (to be reported in a subsequent *Newsletter* article) confirm this change in swimming behavior.

Table 2
ENDURANCE (*median and range*) AND TIME OF FIRST IMPINGEMENT (Imp1) OF DELTA SMELT SWIMMING AT DIFFERENT VELOCITIES

	Velocity					
(cm/s)	5	10	15	20	25	30
(n)	(10)	(16)	(15)	(20)	(15)	(7)
Endurance (min)	360 254-360	360 3-360	64 2-360	51 2-360	50 1-360	11 2-360
Imp1 (min)	292 5-360	144 2-360	16 1-196	16 2-200	49 1-360	6 2-360

Because of these factors, we do not recommend direct application of these results to develop approach velocity criteria for delta smelt. Such use may seriously misinterpret the true performance of the fish in flow regimes like those near diversions. We believe another approach is necessary, using methods and equipment that more accurately simulate diversion flow regimes and provide the fish with adequate space in which to express appropriate behaviors. We are currently developing this project in collaboration with the UC-Davis Hydraulics Laboratory and the Department of Water Resources, and we look forward to reporting our results in this *Newsletter.*

Acknowledgments

Many people contributed to the success of this project. We thank R. Mager and S.I. Doroshov (Department of Animal Science, UC-Davis) for their help developing techniques for collection of delta smelt. We also thank the Department of Fish and Game, particularly D. Sweetnam, G. Aasen, J. Lott, and the bay/delta boat crew, for their invaluable cooperation and assistance collecting delta smelt. Our undergraduate and graduate research interns who helped with fish collection, fish care, and data collection deserve special thanks — T. Chen, S. Cummings, D. Irwin, M. Gonzalez, J. Lorenzo, L. Minium, P. Moberg, C. Myrick, C. Porter, D. Shigematsu, M. Thibodeau, and S. Vandepeute. The Delta Smelt Screen Criteria Workgroup, which includes T. Frink, D. Hayes, L. Winternitz, S. Spaar, D. Sweetnam, D. Odenweller, P. Raquel, S. Griffin, P. Coulston, R. Pine, and M. Vandenberg, provided useful comments on early presentations of these results. We thank the Department of Water Resources and R. Brown for supporting this work.

References

Brett, J.R. 1964. The respiratory metabolism and swimming performance of young sockeye salmon. *J. Fish. Res. Bd. Can.* 21:1183-1226.

Clay, C.H. 1995. *Design of Fishways and Other Fish Facilities.* Lewis Publishers, Boca Raton. 248 pp.

Moyle, P.B., B. Herbold, D.E. Stevens, L.W. Miller. 1992. Life history and status of the delta smelt in the Sacramento-San Joaquin Estuary, California. *Trans. Am. Fish. Soc.* 121:67-77.

Pearce, R.O., and R.T. Lee. 1991. Some design considerations for approach velocities at juvenile salmonid screening facilities. *Am. Fish. Soc. Symp.* 10:237-248.

Swanson, C., and J.J. Cech, Jr. 1995. *Environmental Tolerances and Requirements of the Delta Smelt, Hypomesus transpacificus.* Final Report, Department of Water Resources. 77 pp.

U.S. Fish and Wildlife Service. 1994. Formal Consultation on the 1994 Operation of the Central Valley Project and State Water Project: Effects on Delta Smelt. 50 pp. with figures.

Delta Outflow

Kate Le (DWR)

During April and May, the Delta Outflow Index averaged about 36,000 cubic feet per second. Outflow peaked to about 99,000 cubic feet per second due to a major late-season storm in the latter part of May. Combined SWP/CVP pumping for April and May averaged about 6,000 cubic feet per second. Around June 12, inflow into Clifton Court Forebay was stopped to accommodate herbicide treatment. An introduced species, *Egreria densa,* growing in the forebay is causing problems at the fish salvage facilities, as well as at the pumps.